Cathodic Protection Attenuation Near Tidal Zone Area

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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In partial fulfilment of the requirement for the
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Approved by,

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
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May 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

_____

AMIRAH HUSNA BINTI ABDUL HALIM

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Sincerely,

Amirah Husna

ABSTRACT

Pipeline is widely used in the offshore industry to transport all the oil and gas product from the offshore platforms to the onshore facilities. Large investment has been made by most oil and gas company in order to make sure offshore pipelines could last for their design life. So far, cathodic protection system and coating protection are the best solution in order to control the corrosion process along the pipeline. Over the years, cathodic protection has doing great in controlling the corrosion process for all offshore pipeline which either been buried or being laid in the deep water. However, the corrosion problems for pipelines near tidal zone area seems to have been overlook by the people in this industry. All these years, pipeline coating has been widely used in order to protect the pipeline in the tidal zone area.

Generally, this research will study and analyze the response of cathodic protection system near tidal zone area. It will focused more on finding out the cathodic protection potential at tidal zone area close to shoreline. A few equations is being used and adapted with cathodic protection design from PETRONAS PMO in order to find out the dissipation of cathodic protection potential at tidal zone area. It seems that sacrificial anode does not function effectively in tidal zone area due to the absence of stable seawater electrolyte. Sacrificial anode needs a stable electrolyte around the metalwork to enable the anode to function effectively.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Over the years, there are more than 27, 000 miles of offshore pipelines have been laid on the seabed of the ocean since 1859. All these pipelines had either been abandoned in the sea or had been removed. These pipeline were used to transport all the petroleum product from the topside facilities to the processing facilities. Normally, offshore steel pipelines are designed for a life span ranging from 10 years to 40 years. In order to make the pipelines to last for such life span, these pipelines need to be protected from corrosion both externally and internally.

Corrosion has become one of the biggest concern for all oil and gas companies. The effect of corrosion could lead to pipeline leakage and ruptures, which is the most crucial problem that all oil and gas companies need to avoid. They have to put in much effort and money to overcome this problem. Although corrosion could not be eliminated but it can be reduced to some extent. One of the solution in reducing the rate of corrosion on the pipeline is by applying the coatings or protection systems that could slow down or inhibit the rate of corrosion on the pipeline.

From the early years of offshore industries until mid-1970's, all the offshore pipeline coatings had been using either asphaltic or aggregate 'Somastic' type coating or the hot-applied coal tar enamels. After that, the trends had change into using the Fusion Bonded Epoxy (FBE) powder coatings. Later then, cathodic protection was introduced and widely used in the oil and gas industries.

Cathodic protection (CP) is a method of controlling the metal surface by preventing the corrosion of parent metal. A sacrificial anode is provided in order to prevent the damaged areas from corroding. In the early days, CP relied on the impressed current-system that consist of DC power source, an AC powered transformer rectifier and an array of anodes that were buried in the ground. In early 1970s, the zinc bracelet anode that were attached to the pipeline were introduced and since then, it had been widely used by many operators. After many researches were done by the earlier researcher, it was found that aluminum alloy perform much better as compared to zinc bracelet anode. Since then, aluminum alloys had become the preferred material for the offshore pipeline galvanic anode. However, there are still some operators that used impressed current-systems and zinc bracelet anode in their pipeline external protection.

1.2 Problem Statement

Pipeline plays an important role in the oil and gas industries. Until now, pipeline has become the most efficient and economical transportation for the crude oil, natural gas and their product. Despite of its efficiency, the corrosion in the internal and external surface of the pipeline has become the main concern for the people in this industry.

Many research and studies have been done in order to find out the solution for this problem. Until now, the best solution they can find is by applying the cathodic protection and coatings to the offshore pipeline. Yet, the application of cathodic protection and coatings is just a matter of slowing down the corrosion of the pipeline. Usually, the most severe pipeline corrosion occurs in the splash and tidal zone area where the corrosion rates are generally more than twice compared to the pipeline that immersed in the ocean. Thus, some analysis should be done in order to find out the dissipation of CP near the tidal zone area. In this research, a qualitatively analysis will be conducted in order to find out the CP responses near tidal zone area.

The figure below shows the illustration of the offshore pipeline near tidal zone area. In the figure, Section 2 area which is the shore-water interface shows clearly the pipeline laying at the tidal zone area.

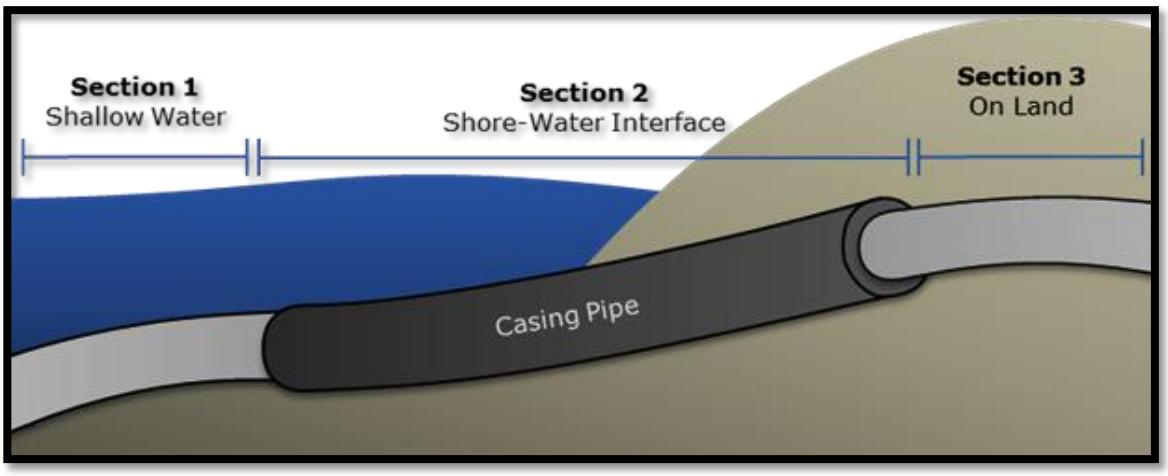

Figure 1: The illustration of the pipeline near tidal zone area.

1.3 Objectives and Scopes of Study

The objectives of this research are:

1) To calculate and compare the cathodic protection distribution along the pipeline near tidal zone area.
2) To qualitatively analyze the dissipation of cathodic protection near tidal zone area.

In general, the scope of study for this research is to analyze the cathodic protection potential prediction near tidal zone area close to shoreline. In this research, the corrosion in the pipeline will not be used for validation as the data provided is very limited. The calculation of cathodic protection potential was calculated based from the formula used by past researchers. Therefore, the scope of works for this research will include the analysis and observation of the cathodic protection potential dissipation and behavior near tidal zone area.

CHAPTER 2

LITERATURE REVIEW

Pipeline systems are very important assets in oil and gas industries. They are mainly used to transport all the petroleum product like crude oil and natural gases from the topside facilities to the processing facilities. All oil and gas companies are trying very hard to come out with the best pipeline design that could last longer. In order to have the best offshore pipeline design, they need to overcome the issue of pipeline corrosion both externally and internally. Ever since years ago, corrosion has become the biggest enemy in the oil and gas industries. Corrosion problems could lead to pipeline leakages and ruptures in which would cause disaster if it is happening.

Generally, corrosion is defined as the common phenomenon where materials deteriorates due to the reaction with the environment. According to the Theory of Corrosion and Cathodic Protection by J.B. Bushman (n.d.), different terms have been used in order to describe the form or basic mechanism of corrosion. He preferred to defined corrosion as the degradation of materials when they reacts with the environment. On the other hand, based on ISO 8044, Corrosion of Metal & Alloys, corrosion is defined as the physiochemical interaction between metal and its surrounding environment which will result in the changes in properties of the metal itself.

Normally, all metal are naturally found in corroded state in which they are in their most stable state of metals. Corrosion process occurred when the metal change to oxide state or as well as their stable state. In order for the corrosion process to occur, there are several component that need to be taking into consideration. They are the anode, cathode and electron path or ionic path. During corrosion process, anodic and cathodic reaction will be occur in which they are representing the oxidation and reduction process. As for the electrons or ionic path, this terms shows the condition of the environment where the electron or ions is moving or transferred during the corrosion process.

Theoretically, corrosion process will occur when the metal react with the environment where there are the presence of water and oxygen. Corrosion reaction will significantly increase in the aqueous solution due the presence of dissolved salt, acids, or bases which create and electrically conducting with the alliance of electrolytes. Marine water environment is an exact example of electrolytic solution which significantly related to various kind of corrosion failure experienced by numerous marine structures like offshore platforms, bridges, ship and pipelines. According to Fontana (1986), he had stated that corrosion rate will significantly increase in a corrosive solution such as the sea water. The corrosion rate is increase as the concentration of the corrosive solution is increased. Sea water is one of example for the corrosive solution as it contains various kinds of salts, mainly sodium chloride, NaCl

2.1 Corrosion at Tidal Zone Area

Marine environment can be divided into different zones. Usually, these zones were divided based on the water level and conditions. Some of the zones in marine environment are splash zone, high zones and mid zones. Yin et al. (2008) has stated that the marine environments can be divided into atmospheric, splash, tidal, seawater and sea mud zones, This has also been supported by Zen (2005), as he had mentioned that the corrosion environment for all port structure are usually divided into atmospheric, splash, tidal, seawater and mud and backfill zones.

Over the years, the rate of corrosion along the splash and tidal zone area has been very severe. It is reported that the rate of corrosion in splash and tidal zone area is twice greater compared to any zones in the marine environment. Jeffrey and Melchers (2009) had stated that based from the past research done by Humble, LaQue and Larrabee on the corrosion loss mass profile, the result for the steel exposed in marine tidal conditions for short terms (151 days) and longer terms (5 years) has shown the very similar profile pattern in which the most severe corrosion occurred in the tidal zone area that is, the region above the mean-tide level. This has proved the statement from Bardal (2004) as he also stated that the corrosion damage is likely to be most severe in the splash and tidal zone area. Besides that, Zen (2005) also has said that 'the corrosion rate in the atmospheric zone is less than 01.mm/year while the corrosion rate in the tidal zone is about 0.3 mm/year'.

Past research done by various researchers were only to observe and study the corrosion rate in the tidal zone at the bridges, piles and offshore platform. This can be seen as Kaplan et al. (1995) has presented and came up with the analytical solution to the wave slamming impact on the offshore platforms. Besides that, Zen (2005) has examined the corrosion tendency of a steel pile at the portion between 'mean low water level' and 'low water level'.

Based from my observation, there is none research has been done to investigate the cathodic protection behavior along the pipeline at tidal zone area. Nevertheless, Lye (2001) has stated that according to the old Det Norske Veritas rules, the risers at the

splash zone area will have a corrosion protection allowance for 2 years. He also stated that the corrosion allowance is always depended on the operating temperature and should be less than 2mm corrosion area. The philosophy that they usually used is that if the coating protection is damaged, it must be repaired within 1 to 2 years period. He also stated that the minimum corrosion rate for the riser is anticipated at 1mm/year. Apart from that, M. Khalil and Abdel-Gaber (2014) has studied on the effectiveness of cathodic protection extension on steel piles at tidal and splash zone areas, which is by laboratory simulation test. They had conclude that a long term cathodic protection can be achieved on both bare and coated steel at the proposed tidal and splash zones area. Furthermore, Chen, Huang and Dong (2012) has stated that an alternative corrosion protection method has been used in splash and tidal zone area. Coating layer of Ni-Cu alloy, Zn-Al alloy and heavy-duty coating has always been used to protect offshore structures at splash zone area. This has been supported by Creamer (1970) as he had stated that in early 1949, Ni-Cu coating has been utilized on offshore platform in Gulf of Mexico and for the last 50 years the alloy has been applied to many legs and rises of many offshore structures. The figures below shows the corrosion that are usually occur on bridges, piles and offshore platforms in the tidal zone area.

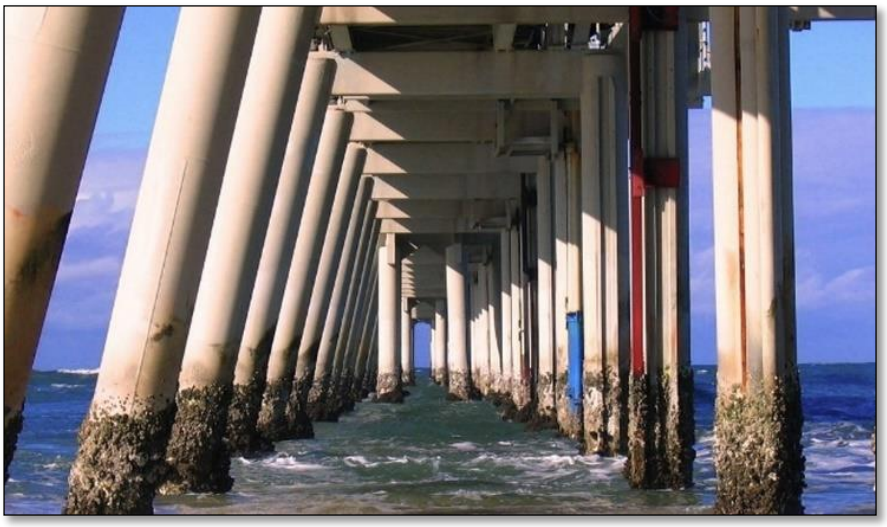

Figure 2: Corrosion of bridge in tidal zone area

(Source: Norfolk Marine)

Figure 3: Corrosion of piles in tidal zone area

(Source: Cumberland)

Figure 4: Corrosion of offshore platform

(Source: Marktool.com)

2.2 Cathodic Protection

Cathodic protection (CP) was first introduced by Sir Humprey Davy in 1824 to protect the copper sheeting on the hulls of the wooden naval ships. According to ISO 8044, CP can be defined as "electrochemical protection by decreasing the corrosion potential to a level at which the corrosion rate of the metal is significantly reduced" while NACE RP0176 has defined CP as "a technique to reduce corrosion of a metal surface by making that surface the cathode of an electrochemical cell". CP is applicable for all types of metals and alloys that were commonly used in marine environment. It prevents localized forms of corrosion as well as uniform corrosion attacks and eliminates the possibility of having galvanic corrosion when the metallic materials with different electrochemical characteristic are combined.

The principles of CP can be explained by referring to the corrosion of a typical metal, M, in an acidic environment. By means of electrochemical reactions, the process of metal dissolution and hydrogen gas evolution occurred, for example:

$$M \rightarrow M\ n+ + ne \quad (1)$$

$$2H+ + 2e \rightarrow H2 \quad (2)$$

CP is achieved as the metal structure to be protected is supplied with electrons, or in other hand, CP system is accomplished by providing external current to the protected structure. Based from the Equation (1) and (2), it shows that addition of electron to the metal will help to a smoother metal dissolution as well as increasing the rate of hydrogen evolution. In other words, the protected structure will be protected from corrosion if the electric current from the electrolyte corrode other metal that has higher negativity compared to the protected structure.

According to Refait et al. (2014), in most cases, all the seaport structures, sheets and pilings were initially not protected against corrosion. In order to increase the lifetime and protect the existing structures, a decision to apply CP is always been considered. Moreover, Saberi et al. (2014) also suggests that CP is one of the primary method in controlling the corrosion which can applied extensively in offshore oil and

gas industries for the submerged metal structures. In general, CP can be applied in two methods which are impressed current systems and sacrificial anode systems. Both types of CP is used to inhibit corrosion but they are very different in terms of their operation.

2.2.1 Impressed Current Systems

Impressed current system is a system that consist of anodes that were connected to direct current (DC) power source. This system provides DC current to the anode through the use of an alternating current (AC) to the DC conversion device, commonly called as rectifier. Normally, DC power source would have a DC output up to 50 amperes and 50 volts. The rectifiers are specified to the current requirement and the driving voltage that are extremely high. The positive DC output terminal will be connected to the anode while the negative terminal is connected to the rectifier. The output of the DC power source will then be adjusted to the optimum level after conducting various test including measurement of the potential electrode. The electric current that were continuously regulated and monitored by this system aids in preventing the electrochemical mechanism of galvanic corrosion prior to its attack. This system is normally used in many seawater systems. The figure below shows the illustration of the impressed current system.

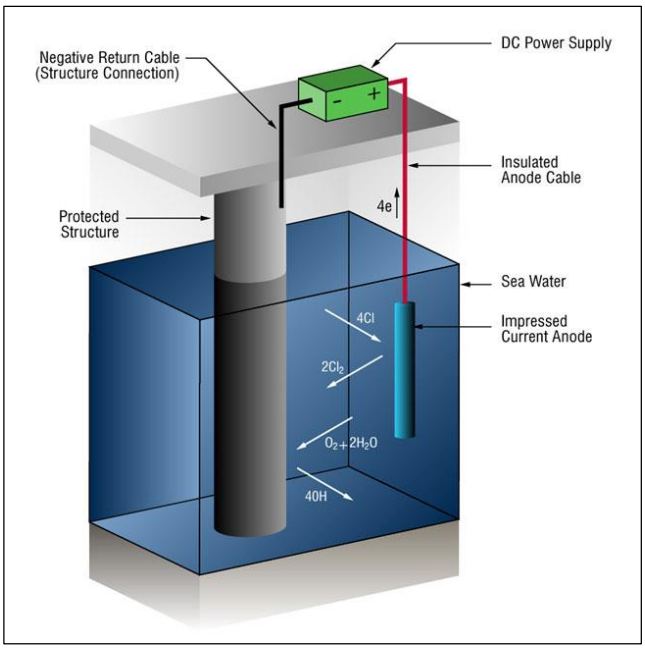

Figure 5: Illustration of impressed current cathodic protection systems

(Source: Deepwater 101)

2.2.2 Sacrificial Anode

Sacrificial anode or usually known as galvanic anode is a system that provides direct current to other metal through the natural potential difference voltage between two materials. Sacrificial anode are created when the metal with more negative electrochemical potential is attached with the less active metal. In this place, the highly active metal will be consumed first in place of the less active metal it is protecting, which is why they were usually referred as a 'sacrificial' anode. Normally, the material used for sacrificial anode is pure active metals like zinc, magnesium or aluminum alloys.

Based from the Offshore Pipelines written by Gou et al. (2005), zinc anodes are not normally used in the deep water pipeline due to their less efficiency. Thus it need a larger mass in order to protect the pipeline system in the deep water. On the other hand, aluminum anodes have perform much better compared to the zinc anodes. They are more suited for a hot buried and deep water pipeline. The figure below shows the illustration of the sacrificial anode system.

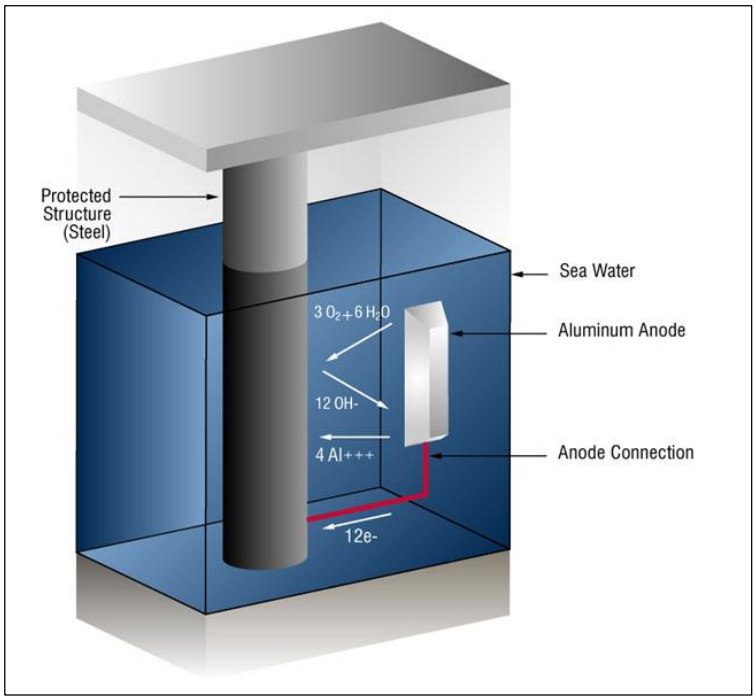

Figure 6: Illustration of Sacrificial anode cathodic protection system

(Source: Deepwater 101)

2.2.2.1 How sacrificial anode works.

Normally, sacrificial anode are being supplied with lead wire or cast m-straps. This is to facilitate the connection between the anode and the protected structure. These low resistance wire helps in the movement of the electron from cathode to anode. Since sacrificial anode works by introducing other metal surface that has more electronegativity, the current will flow from the anodic metal to the protected metal that has become cathodic thus, creating galvanic cell. The polarization of the target structure is caused by the flow of electron from cathode to anode. The higher difference in electrode potential between anode and cathode is much better in this system.

Table 1 shows the potential difference (in volts) when the metal is used as anode with respect to the copper as cathode and being immersed in $CuSO_4$ electrolytes.

Metal	Potential difference with respect to Cu:$CuSO_4$ (volts)
Carbon, Graphite, Coke	+0.3
Platinum	0 to -0.1
Mill scale on Steel	-0.2
Copper, brass, bronze	-0.2
Mild steel in concrete	-0.2
Lead	-0.5
Cast iron (not graphitized)	-0.5
Mild steel (rusted)	-0.2 to -0.5
Mild steel (clean)	-0.5 to -0.8
Commercially pure aluminum	-0.8
Aluminum alloys (5% zinc)	-1.05
Zinc	-1.1
Magnesium alloys (6% Al, 3% Zn, 0.15% Mn)	-1.6
Commercially pure Magnesium	-1.75

Table 1: Simplified galvanic series

2.3 Cathodic Protection Design for Pipeline

According to Det Norske Veritas, cathodic protection (CP) can be defined as electrochemical protection by decreasing the corrosion potential of the protected structure to a level in which the corrosion rate is significantly reduced. Based from the design philosophy of Petronas Technical Standard; Design of Cathodic Protection System for Offshore Pipeline, it stated that all offshore pipeline should be protected from corrosion using a mixed use of external coating and cathodic protection. Petronas also recommended CP system to be used in the new offshore pipelines that features a bracelet-type sacrificial anode. This also supported by Zhang et al. (2012) as they also said that CP is a best practice in impeding the metal structure form corrosion.

In designing a cathodic protection, there are several design parameters that should be taken into consideration. Based from the Recommended Practice DNV-RP-BR401; Cathodic Protection Design, the design parameters to be used in the conceptual and detailed design of CP systems are design life, design current densities, coating breakdown factor, material design parameter, anode resistance, seawater and sediment resistivity and current design parameter. Petronas Technical Standard also followed the same design parameter as the DNV Code of practice but with some modification in the design current densities and the coating breakdown factor.

2.3.1 Design Current Densities

Design current density, i_c refers to the cathodic protection current per unit surface area (A/m^2). The current density need to achieve its full protection of a bare metal depends on the sea water temperature water velocities. Once the current demand is calculated, it will then be used to determine the number and size of anode. On this matter, both PTS and DNV code have different sets of data. The data used in PTS are usually applicable to the North Sea and the Norwegian Sea up to a latitude of 70 degrees North while the data used in DNV are used with the consideration of polarization effect of bare metal surface and the establishment of calcareous scale and marine growth. The tables below will show the current density for PTS and DNV code of practice.

	Design current density, mA/m^2		
Sea water temperature	Low lateral water flow / turbulence	Moderate lateral water flow / turbulence	High lateral water flow / turbulence or depth < 20m
> 20 °C (Tropical waters)	50	60	70
12-20 °C (Sub tropical waters)	60	70	80
7-12 °C (Temperate waters)	70	80	100
< 7 °C (Arctic waters)	90	100	120

Table 2: Design of current densities of non-buried offshore pipeline in different sea water condition (from PTS code of practice)

Depth (m)	**Tropical (> 20 °C)**	**Sub-tropical (12-20 °C)**	**Temperate (7-12 °C)**	**Arctic (< 7 °C)**
0-30	0.070	0.080	0.100	0.120
> 30-100	0.060	0.070	0.080	0.100
> 100-300	0.070	0.080	0.090	0.110
> 300	0.090	0.100	0.110	0.110

Table 3: Design current densities (A/m^2) for seawater exposed bare metal surface based on surface water temperature (from DNV code of practice)

2.3.2 Coating Breakdown Factor

Coating breakdown factor, f_c is described as the reduction factor in the cathodic current density due to the application of electrically insulating coating. Coating breakdown factor is calculated as:

$$f_{cm} = 1 - \frac{(1-a)^2}{2 \,.\, b \,.\, t_f}$$

Where f_{cm} = coating breakdown factor

a & b = constant factor

t_f = CP design life

In PTS code of practice, both the constants factor is changed to k_1 and k_2 while the CP design life is changed to $f_{c(average)}$ / $f_{c(final)}$. Table below shows the constants (k_1 and k_2) for calculation breakdown factors for different pipeline coatings.

COATING TYPE	K_1	K_2	Example for 20 year design life ($f_{c(average)}$ / $f_{c(final)}$)
Asphalt and concrete weight coatings	0.02	0.004	0.04 / 0.10
FBE + adhesive + Polyethylene or Polypropylene	0.02	0.002	0.04 / 0.06
Polychloroprene / EPDM	0.01	0.002	0.03 / 0.05
Thermally insulated pipelines	0.01	0.001	0.02 / 0.03
Fusion bonded epoxy coating without mechanical protection	0.05	0.005	0.10 / 0.20

Table 4: Constant of k_1 and k_2 for different pipeline coatings.

In DNV code of practice, pipeline coatings are categorized into 3 category. The table below shows the constants for calculation of coating breakdown factors.

Depth (m)	Recommended a and b values for Coating Categories I, II and III		
	I (a = 0.10)	II (a = 0.05)	III (a = 0.02)
0-30	b = 0.10	b = 0.025	b = 0.0012
> 30	b = 0.05	b = 0.015	b = 0.008

Table 5: Constant a and b for different coating categories.

Category I	One layer of epoxy paint coating, min. 20 μm nominal DFT.
Category II	One or more layer of marine paint coating (epoxy, polyurethane or vinyl based), total nominal DFT min. 250 μm.
Category III	Two or more layers of marine paint coating (epoxy, polyurethane or vinyl based), total nominal DFT min. 350 μm

2.4 Wave Transformation and Attenuation

Normally, ocean waves are generated naturally by the action of wind on water. They were formed initially through a complex process of shearing action and resonance. In the process, these waves will have difference wave height, length and period that were travelling in various directions. Once the waves is formed, they will travel for a far distances, spreading in various direction and reducing in wave height, but it will maintaining same wavelength and period. As the waves approaching shoreline area, their height and wavelength will be altered due to some process that were happened.

The accurate computation of nearshore wave transformation is a major aspect of the design of coastal structures and the prediction of nearshore currents and shoreline changes. As the waves approaching the shoreline, the waves will enter a transitional depth region in which these waves motion will be affected by the ocean seabed. They will undergo several processes such as refraction, shoaling, bottom friction, and wave breaking (Reeve, Chadwick and Fleming, 2012). If the waves encounter with major structures or abrupt changes in the shoreline, they will be transformed by diffraction process. According to Chen and Tsai (2012) in order to design the coastal structures and predict the shoreline changes, an accurate information and calculation of wave transformation is needed. They also added that in the calculation of complex nearshore wave transformation, the combined effect of wave shoaling, refraction, diffraction, reflection and wave breaking should be included.

2.5 Cathodic Protection Attenuation Design

As for the calculation of CP potential attenuation, several formula used by various researchers has been adapted in this research. Various researchers has come up with their own formula based from the basic formula of CP potential from Morgan and Uhlig. They have been come up with the new equation as to improve and modified the equation to suit better with current conditions.

2.5.1 Cathodic Protection Potential based from Smith (1992)

Smith (1992) has come up with equation based from Morgan's Equation. In this equation, he had assume that the CP of a coated pipeline is receiving current only from one end.

$$E_x = E_a e^{(-\propto x)}$$

where

E_a = 400 mV (assuming typical cathodic protection potentials of -950 mV)

α = attenuation constant = $\sqrt{rg}$

r = electrical resistance of pipe

g = the conductance of coating

The value of r was calculated by:

$$r = \frac{\rho * area}{L}$$

where

ρ = resistivity of steel pipe

area is the cross-sectional area of the pipe = $\pi * \left[\left(\frac{outer\ diameter}{2}\right)^2 - \left(\frac{inner\ diameter}{2}\right)^2\right]$

L is the unit length of pipe and is assume as 1 m

The value for g is not as easily calculated since the quality of the coating, including holidays and damage must be considered. However, a value for g was estimated using the following procedure:

$$g = Xg_{holidays} * (1 - x)g_{coating}$$

where

X is the fraction of the coating surface that is damaged,

$g_{holiday}$ is the conductivity of the polarized layer at the damaged coating sites

$g_{coatiing}$ is the undamaged coating conductivity

Since the conductivity of the coating can be assumed to be several orders of magnitude smaller than the conductivity of the polarized layer in the coating holidays, a simplifying assumption can be made that:

$$g = Xg_{holidays}$$

The polarized layer conductivity at the holidays can be estimated by:

$$g_{holidays} = \frac{1}{\left(\frac{E}{I} * \frac{Surface\ Area}{Length}\right)}$$

where

E = driving voltage

I = current in amperes

Surface area is the surface area of a unknit length of pipe

Length is the distance current must flow to the pipe and is assumed as the thickness of the polarized layer.

2.5.2 Cathodic Protection Potential based from Fontaine and Gibson (2004)

Fontaine and Gibson (2004) has come up with the equation of CP potential based from Uhlig's Equation. They had assume that the change in polarization is linearly proportional to the current density. They also assume that Uhlig model accurately predicts that attenuation along the pipeline and the coating damage along the length of pipeline is uniform.

$$E(x) = MPP * cosh\left[B * \left(x - \frac{L}{2}\right)\right] + E_{corr}$$

where

MPP = the mid-point polarization

L = the length of pipeline between anodes or drain points

E_{corr} = Free corrosion potential of steel (typically -630 mV)

B = the 'pipeline attenuation constant'

B is given by:

$$B = \sqrt{\frac{\pi . d . R_L . \%b}{P}}$$

where

d = outer diameter of the pipeline

R_L = electrolyte resistivity

%b = coating breakdown factor

P = polarization resistance

2.5.3 Cathodic Protection Potential based from Hartt and Lysogorski (2003)

Hartt and Lysogorski has come up with the equation of CP potential based from the projection classical equations of Morgan and Uhlig. In this equation, they have assume that the pipelines is polarized by identical, equally spaced anodes.

$$E_c(z) = E_b.cosh\left[\left(\frac{2\pi r_p.R_m}{k.\zeta}\right)^{1/2}.(z-L)\right]$$

where

E_b = CP potential (assume 400 mV)

r_p = pipe radius

k.ζ = current density demand

L = half anode spacing

R_m = pipe resistance per unit length $= \frac{\rho_m}{Area}$

where

ρ_m = metal resistivity

Area is the cross-sectional area of the pipe

However, in this equation the anode resistance does not appear explicitly. If the pipeline lies within the anode potential field, an inaccurate projections of potential-distance relationship is likely to result.

2.5.4 Cathodic Protection Potential based from Hartt and Lysogorski (2003)

Hartt and Lysogorski also has come up with another equations in their research. In this equation, they have considered a linear relation between the polarized pipe potential and cathode current density. They also have assume that the pipeline is protected by multiple, equally spaced, identical superimposed bracelet anode. The bracelet anode is assume to have incorporated all four resistance which are anode electrolyte, coating, polarization and metallic path.

$$E_c(z) = \alpha.\gamma.i_c(z)$$

where

α = polarization resistance

ϒ = coating breakdown factor

i_c = cathode current density

CHAPTER 3

METHODOLOGY and PROJECT WORK

3.1 Overall Methodology

This research involves in several stages with the first stages is to study and identify the current design and the performance of CP application. Some of the areas that can be improved will be then identified and being put into consideration as the base hypothesis for this research. Then, the CP potential near tidal zone area will be computing. In this stage, several equations and formulas from various researchers will be used. The design parameters used by PETRONAS PMO will be adapted into all the equations. After that, the results from all the calculation will be compared and analyze qualitatively in order to find out the guideline for the placement of CP near tidal zone area. Figure below shows the simplified of project's methodology.

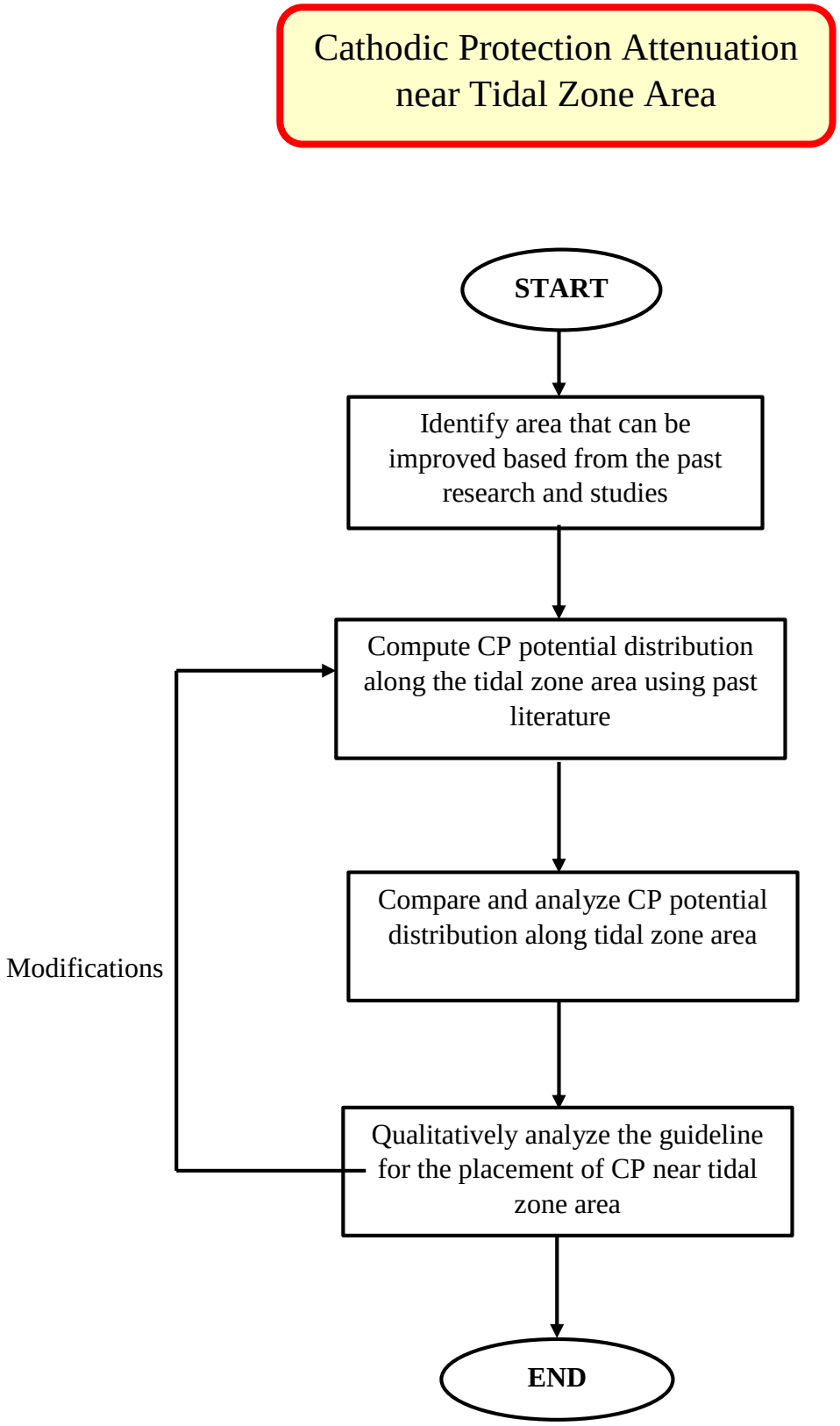

Figure 7: Methodology of project

3.2 Detailed Methodology

This research involves a qualitative analysis for the CP distribution near tidal zone area. Further studies has to be conducted beforehand to provide a better understanding. Therefore, the research method and activities planned are conducted as follow.

1. Research and Literature Review.

   The aim of this activity is to study about the previous research done by other people. This is to instill some awareness and understanding of the current situation related to this research. Method used in this activity is by collecting and reading all journal articles, online materials, books and other source of reading materials that are related closely to this research.

2. Computing of CP Potential Distribution.

   The objective of this activity is to compute the CP potential distribution at tidal zone area. For this activity, the CP distribution will be calculated by using several equations used by various researchers. The design parameters used by PETRONAS PMO will be used and adapted into all the equations involved.

3. Result Analysis and Comparison.

   The objective of this activity is to compare and analyze the result obtained from CP potential distribution. A qualitative analysis will be done in order to find out the best guideline for the placement of CP near tidal zone area at shoreline.

3.3 Project Progress / Timeline

Project progress and timeline is essential in this research. Project timeline will help in making the project to be in track.

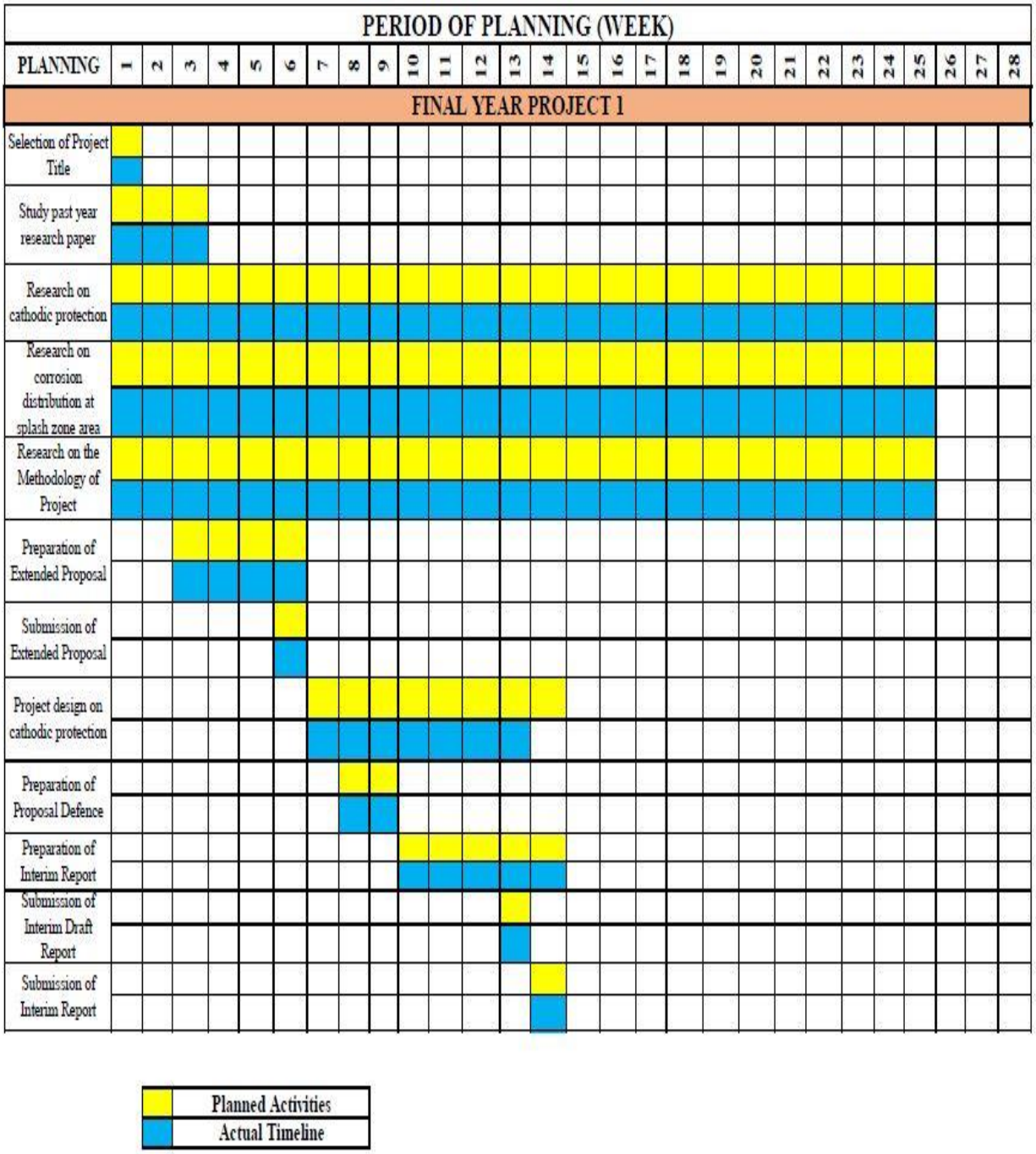

Figure 8: Project planning and timeline for FYP 1

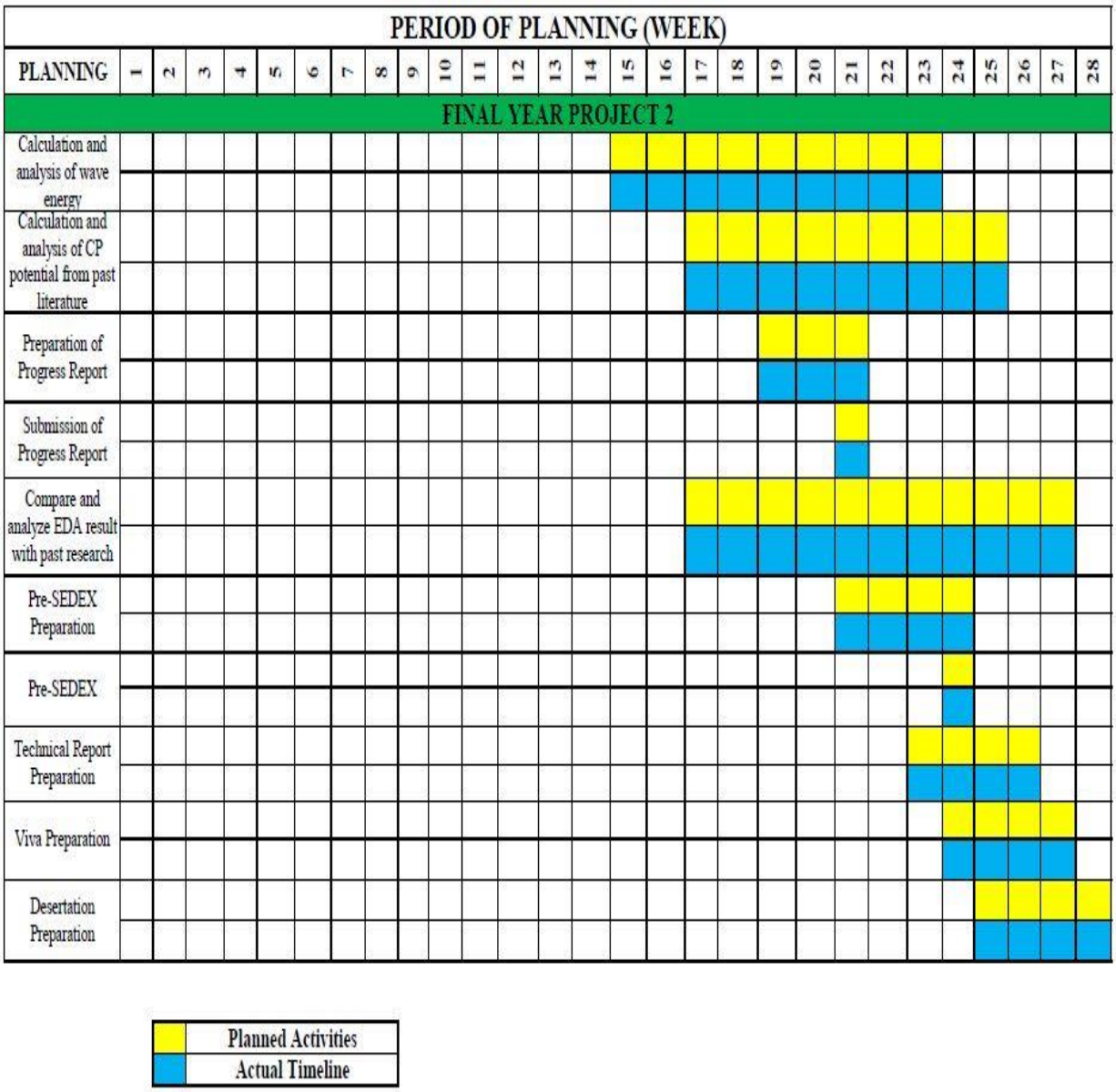

Figure 9: Project planning and timeline for FYP 2

CHAPTER 4

RESULTS and DISCUSSIONS

This research study is comprises of two objectives that are intended to be achieved at the end of the study. In this section, all the results and findings will then be discussed accordingly based from the objectives stated.

In order to find out the CP behavior at tidal zone area, the calculation of CP potential distribution will be done. The aim of this activity is to find out the CP attenuation along the pipeline in the tidal zone area. The calculation of CP attenuation is based from past literatures and formula used by past researchers. Four types of equation used by various researchers will be adapted in this calculation of CP.

Some of the CP parameters used by PETRONAS PMO has been used and adapted in all of the equations.

CP Design Parameters	
Diameter outside	0.468 m
Diameter inside	0.467 m
Wall thickness	0.001 m
Coating thickness	0.003 m
Coating breakdown factor	0.0525 (FBE coating)
Anode spacing	50 m
Current density demand	0.086 A/m^2
Polarization resistance	17.5 Ω.m
Metallic resistivity	1.7×10^{-7} Ω.m
Electrolyte resistivity	25 Ω.m
Driving voltage	200 mV

Table 6: CP Design parameters used by PETRONAS PMO

4.1 Calculation of Cathodic Protection Potential based from Smith (1992)

In his research, Smith has used and derived an equation based from the Morgan equation. He had adapted in the factor that the attenuation of cathodic protection of protected pipeline has been receiving the potential current only from one end. The equation that they used is

$$E_x = E_a e^{(-\propto x)}$$

When we adapted the design parameter into the equations, the result of the finding will be as follow.

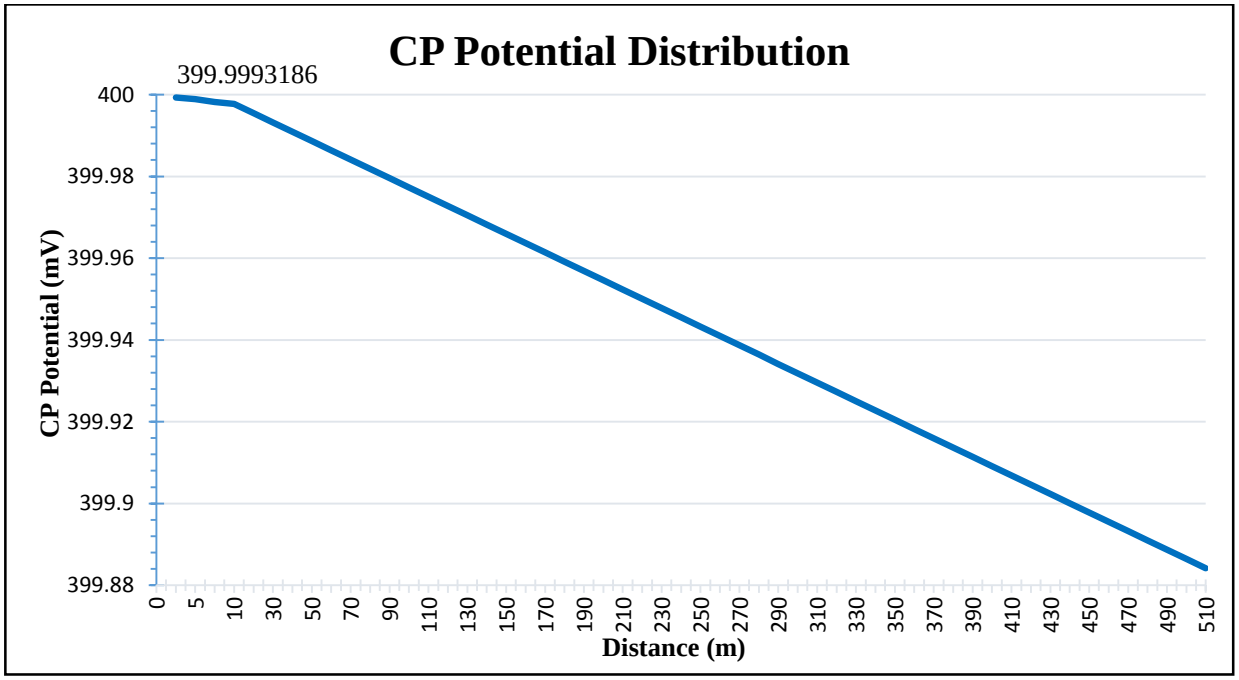

Figure 10: Graph of CP potential based from Smith Equation

Based from the graph, we can see that the CP potential distribution is decreasing linearly. The initial CP potential is recorded around 399.99 mV. Then, we can see that as the distance is further away from shoreline area the CP potential is decreasing linearly.

The lowest CP potential is recorded around 399.88 mV which located at 500 m away from shoreline area. In this results, we can see that the CP potential which received the current at its end will likely have a higher potential. As the distance is further away, the CP potential will be decreasing in order to protect the other end of pipeline. In this equation also, the CP near shoreline area has been receiving the potential current. This shows that the CP near shoreline area need some 'kick-start' of current potential in order for the anode to protect the pipeline in shoreline area.

4.2 Calculation of Cathodic Protection Potential based from Fontaine and Gibson (2004)

In the research, Fontaine and Gibson has used and derived an equation based on Uhlig's Equation. They had assume that the change in polarization is linearly proportional to the current density. The equation that they has used is

$$E(x) = MPP.cosh\left[B.\left(x - \frac{L}{2}\right)\right] + E_{corr}$$

As the equation used by Fontaine and Gibson is used and adapted with the CP design parameter from PETRONAS PMO, the results produced is as follow.

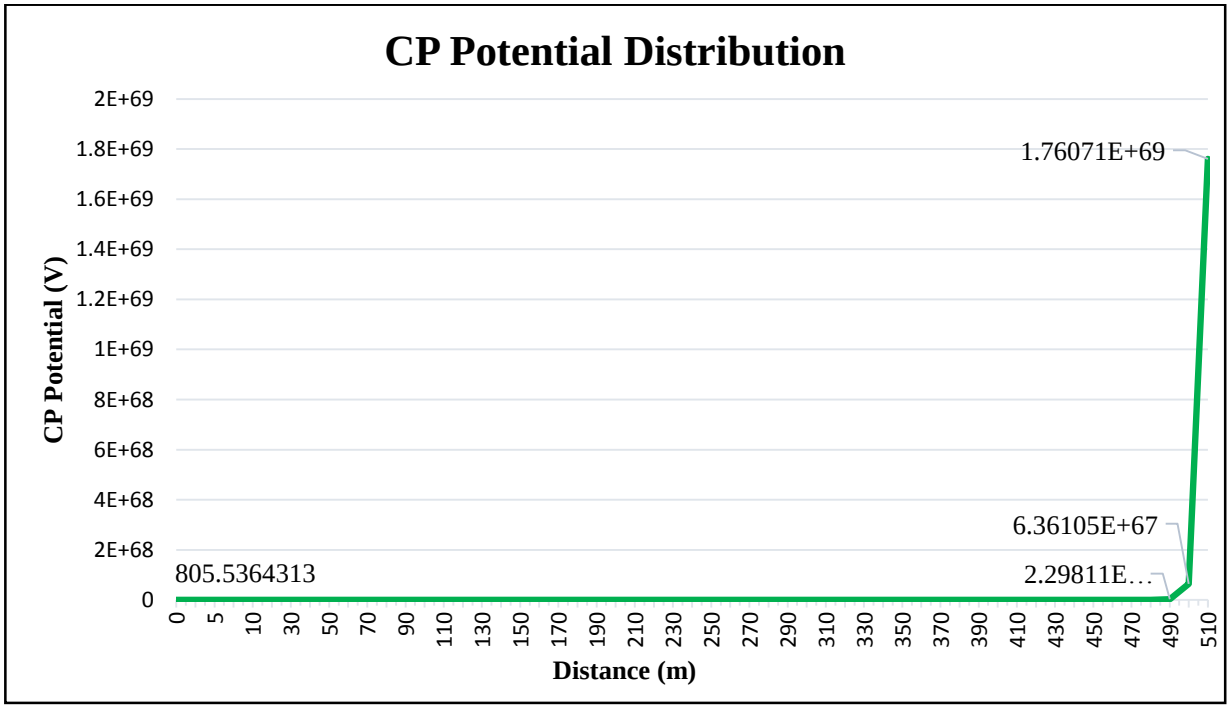

Figure 11: Graph of CP potential based from Fontaine and Gibson Equation

Based from the graph above, we can see that the CP potential is increasing as the distance from shoreline is further away. The initial CP potential recorded is around 805.53 V. As the distance from shoreline area is further away, the CP potential keeps on increasing. The highest CP potential is recorded around 1.761×10^{69} which is at 510 m away from the shoreline area.

We can see that the results based from Fontaine and Gibson equation is totally differ from the result based from the equation used by Smith. In this equation, the CP potential is produced naturally as compared to the Smith equation. This makes the CP potential near shoreline area to be small when compared to CP potential based from Smith's Equation.

4.3 Calculation of Cathodic Protection Potential based from Hartt and Lysogorski (2003)

In the research, Hartt and Lysogorski has calculate the potential attenuation by using a commonly projected of the classical equations of Morgan and Uhlig. They had assumes that the pipelines are polarized by identical, equally spaced anodes. However, in this equation the anode resistance does not appear explicitly. If the pipeline lies within the anode potential field, an inaccurate projections of potential-distance relationship is likely to result. The equation that they used is

$$E_c(z) = E_b . cosh\left[\left(\frac{2\pi r_p . R_m}{k . \zeta}\right)^{1/2} . (z - L)\right]$$

When we adapted the design parameter into this equation, the results is as follow.

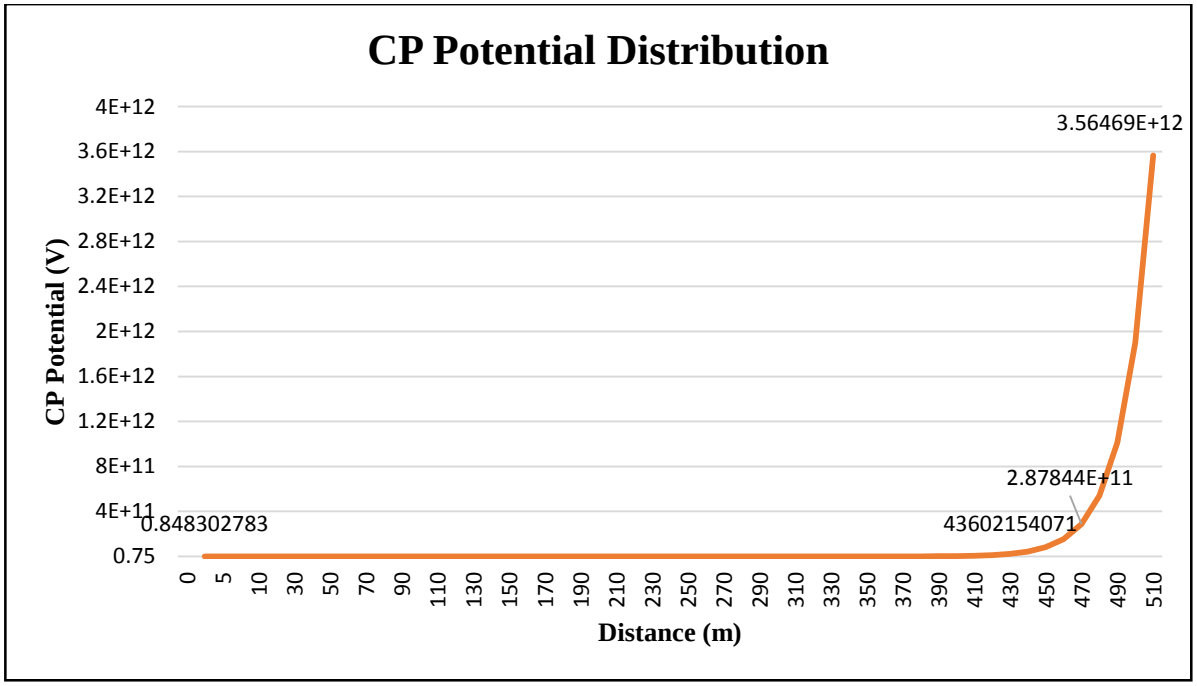

Figure 12: Graph of CP potential based from Hartt and Lysogorski Equation

Based from the graph above, we can see that the CP potential is increasing as the distance from the shoreline area is further away. The initial CP potential is recorded around 0.848 V. As the distance is further away from the shoreline area, the CP potential keep on increasing. The highest CP potential is recorded around 3.56×10^{12} V which is at 510 m away from shoreline area.

We can see that the CP attenuation based on this equation is much likely same with the result from the equation by Fontaine and Gibson. The trends in CP potential from this equation is much differ with the results obtained from the equation used by Smith. The CP potential for this equation also is produced naturally. This has made the CP potential near shoreline area to be small as compared to the CP potential that is further away from shoreline area.

4.4 Calculation of Cathodic Protection Potential based from Hartt and Lysogorski (2003)

Hartt and Lysogorski also had come up with another CP potential equation. In this equation, the CP potential is based from CP potential at drain point. They has assume there is a linear relationship between polarized pipeline potential and cathode current density. They also has assume the potential attenuation will be protected by multiple, equally spaced, identical superimposed bracelet anode. This bracelet anode is assume to have incorporates with all four resistance which are electrolyte resistance, coating, polarization and metallic path. The equation that they used is

$$E_c(z) = \alpha \,.\gamma \,.\, i_c(z)$$

As the CP design parameter is being adapted into the equation, the results is as follow.

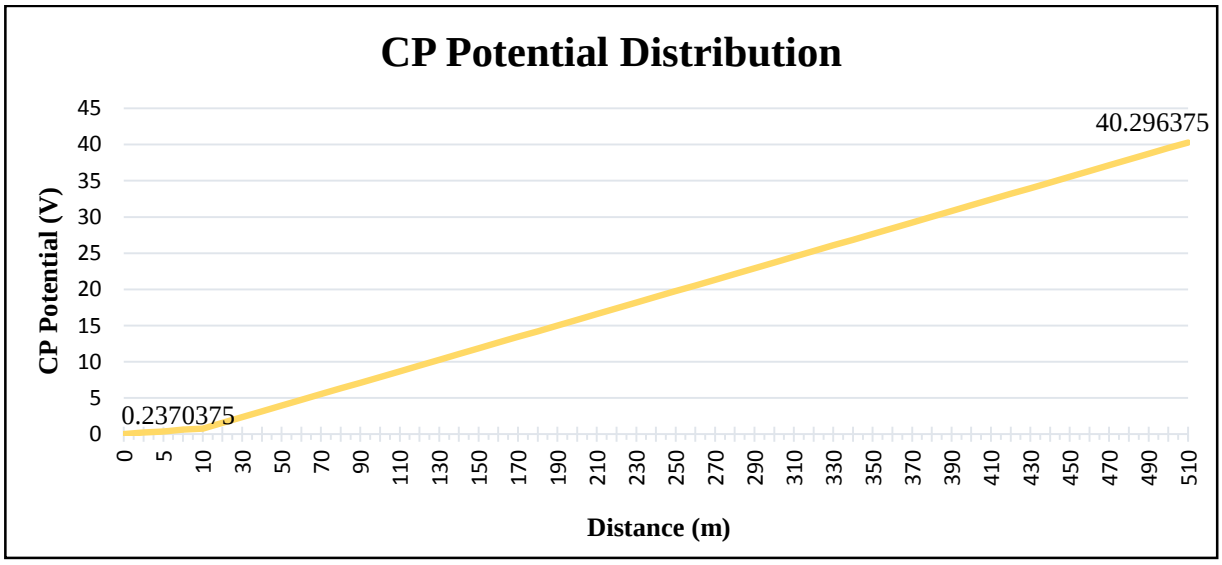

Figure 13: Graph of CP potential based from Hartt and Lysogorski

Based from the graph above, we can see that the CP potential is increasing as the distance from shoreline is further away. The initial CP potential is recorded around 0.237 V. As the distance is further away from shoreline area, the CP potential is increasing linearly. The highest CP potential is recorded around 40.296 V which located around 500 m away from the shoreline area.

We can see that the CP potential recorded when using this equation has the same trends with the other two results. The trends of result shows by this equation is differ when compare with the results from Smith equation.

Based from these four equations, we can see that the trends of CP potential for every equation is much likely same. They will have a lower CP potential when approaching the shoreline area. As the distance is further away from shoreline area, they will have the highest CP potential. Apart from the results based from the Smith Equation, the CP potential for all other equations shows the same trends.

From the results, the CP potential near shoreline area is at the lowest potential when compared to the potential which is further away from shoreline area. This is likely because in shoreline area the movement of wave is always irregular and unpredictable. Pipeline which lays near shoreline area will always experiencing wet and dry condition due to the movement off the waves from the sea.

Sacrificial anode is usually effective when there is a stable electrolyte around the metalwork and have a direct contact with the electrolyte. This is because the presence of seawater as electrolyte will help greatly in the movement of electrons to occur. When there is no stable movement of electron, the sacrificial anode will not work properly and effectively. If a stable seawater film can be formed on the surface of protected structure, then the sacrificial anode will be able to be used in order to protect the parent metal near tidal zone area.

CHAPTER 5

CONCLUSIONS

In conclusion, this research is mainly about the study and analysis of cathodic protection (CP) attenuation along the pipeline near tidal zone area. The calculation for CP potential distribution is done by using various equations by various researchers.

While it is yet to be conclusively proven, based from the results of CP potential calculation, most of them shows that the CP potential near shoreline area will have small potential. From the qualitative analysis of CP potential distribution, it shows that CP potential near shoreline area that having small CP is likely due to the wave activity at shoreline area. As we know, wave activity at tidal zones are very irregular and unpredictable. Sacrificial anode need a stable electrolyte to function effectively. The movement of wave activity will make tidal area to have less presence of stable seawater. This makes sacrificial anode not suited to be installed at tidal zone due to the absence of stable electrolyte.

Recommendation for future works:

1. Apply thicker coating protection at tidal zone area – Based from this research, so far it is advisable for the industry to coat their pipeline with a thicker coating protection since sacrificial anode seems not to function effectively in the tidal zone area.
2. On-site investigation for future works – For future studies about this research, it is advisable that the research to be done more towards on-site investigation. This will help in producing more precise and reliable results as we can observe the behavior and dissipation of cathodic protection at tidal zone area more closely rather than analyzed it qualitatively.

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APPENDIX

The results data of CP potential based from Smith Equation

Distance(m)	CP Potential (mV)
0	0
3	399.9993186
5	399.9988643
8	399.9981829
10	399.9977287
20	399.9954573
30	399.993186
40	399.9909147
50	399.9886435
60	399.9863722
70	399.9841009
80	399.9818297
90	399.9795585
100	399.9772872
110	399.975016
120	399.9727448
130	399.9704737
140	399.9682025
150	399.9659313

160	399.9636602
170	399.9613891
180	399.959118
190	399.9568469
200	399.9545758
210	399.9523047
220	399.9500336
230	399.9477626
240	399.9454915
250	399.9432205
260	399.9409495
270	399.9386785
280	399.9364075
290	399.9341365
300	399.9318656
310	399.9295946
320	399.9273237
330	399.9250528
340	399.9227819
350	399.920511
360	399.9182401
370	399.9159692
380	399.9136984

390	399.9114275
400	399.9091567
410	399.9068859
420	399.9046151
430	399.9023443
440	399.9000735
450	399.8978027
460	399.895532
470	399.8932612
480	399.8909905
490	399.8887198
500	399.8864491
510	399.8841784

The results of CP potential based from Fontaine and Gibson Equation

Distance (m)	CP Potential (V)
0	805.5364313
3	297.0690967
5	152.6009471
8	55.95532426
10	28.49643202
20	0.460240424
30	0.460240424
40	28.49643202
50	805.5364313
60	22313.63357
70	617646.5085
80	17096148.95
90	473212473.1
100	13098273637
110	3.62553E+11
120	1.00353E+13
130	2.77772E+14
140	7.68857E+15
150	2.12816E+17
160	5.89062E+18
170	1.63049E+20

180	4.51312E+21
190	1.24921E+23
200	3.45774E+24
210	9.57085E+25
220	2.64916E+27
230	7.33274E+28
240	2.02966E+30
250	5.61801E+31
260	1.55503E+33
270	4.30425E+34
280	1.1914E+36
290	3.29772E+37
300	9.12791E+38
310	2.52656E+40
320	6.99338E+41
330	1.93573E+43
340	5.358E+44
350	1.48307E+46
360	4.10505E+47
370	1.13626E+49
380	3.1451E+50
390	8.70547E+51
400	2.40963E+53

410	6.66973E+54
420	1.84615E+56
430	5.11004E+57
440	1.41443E+59
450	3.91507E+60
460	1.08367E+62
470	2.99955E+63
480	8.30258E+64
490	2.29811E+66
500	6.36105E+67
510	1.76071E+69

The results of CP potential based from Hartt and Lysogorski Equation

Distance (m)	CP Potential (V)
0	0
3	0.848302783
5	0.760654298
8	0.6514084
10	0.59171194
20	0.419952284
30	0.419952284
40	0.59171194
50	1.005480611
60	1.830488867
70	3.404163458
80	6.370134184
90	11.94147722
100	22.39686087
110	42.01251642
120	78.81120827
130	147.8435288
140	277.3435607
150	520.2765617
160	976.0016496
170	1830.909486
180	3434.655689
190	6443.16929

200	12086.92641
210	22674.21259
220	42535.20696
230	79793.01704
240	149686.0136
250	280800.2943
260	526761.3412
270	988166.7371
280	1853730.378
290	3477466.086
300	6523478.559
310	12237580.89
320	22956829.65
330	43065376.43
340	80787577.18
350	151551737.6
360	284300259.5
370	533327026.5
380	1000483495
390	1876835738
400	3520810094
410	6604788830
420	12390113162
430	23242969325
440	43602154071

450	81794533779
460	1.53441E+11
470	2.87844E+11
480	5.39975E+11
490	1.01295E+12
500	1.90023E+12
510	3.56469E+12

The results of CP potential based from Hartt and Lysogorski Equation

Distance (m)	CP Potential (V)
0	0
3	0.2370375
5	0.3950625
8	0.6321
10	0.790125
20	1.58025
30	2.370375
40	3.1605
50	3.950625
60	4.74075
70	5.530875
80	6.321
90	7.111125
100	7.90125
110	8.691375
120	9.4815
130	10.271625
140	11.06175
150	11.851875
160	12.642
170	13.432125

180	14.22225
190	15.012375
200	15.8025
210	16.592625
220	17.38275
230	18.172875
240	18.963
250	19.753125
260	20.54325
270	21.333375
280	22.1235
290	22.913625
300	23.70375
310	24.493875
320	25.284
330	26.074125
340	26.86425
350	27.654375
360	28.4445
370	29.234625
380	30.02475
390	30.814875
400	31.605

410	32.395125
420	33.18525
430	33.975375
440	34.7655
450	35.555625
460	36.34575
470	37.135875
480	37.926
490	38.716125
500	39.50625
510	40.296375